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Environmental management — Life cycle impact assessment — Examples of application of ISO 14042

Management environnemental — Évaluation de l'impact du cycle de vie — Exemples d'application de l'ISO 14042

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Example 3

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The calculations on a site-dependent basis for the SE indicator result are shown in Table 14. The characterization factors are country-specific, so that the indicator results for the same quantities of emissions now vary considerably (from 1 to 769) depending on where the emission took place. This difference in sensitivity of the receiving regions is not taken into account in the EL indicator, which represents the full potential impacts. Further, only a percentage of the total emission load represented by the EL indicator deposits in areas where the critical load is exceeded. For comparison, then, the number of SO_2 g-equivalents/kt copper from each country deposited in areas where the critical load is exceeded is compared to the 107 SO_2 g-equivalents/kt copper obtained from the EL indicator results.

The two models yield results that are dramatically different! This clearly illustrates the effect of category model and indicator choices between a study goal and scope that needs only general screening results (EL indicator) and one that needs accuracy and environmental relevance (SE indicator).

When using the EL indicator results in the Interpretation phase, a lower level of total emissions from Belgium would at first appear to be environmentally "better" than a somewhat higher level of total emissions from Albania. However, the environmentally relevant SE indicator clearly shows that emissions from Albania would increase the amount by which the critical capacity is exceeded over a far lower area compared to Belgium. Thus, those making decisions involving important comparisons should consider selecting environmentally relevant indicators whose models incorporate spatial information on the emission source, the destination and transport processes, and sensitive ecosystems.

6.4 Example 3 — Impacts of greenhouse gas (GHG) emissions and carbon sinks on forestry activities

6.4.1 ISO 14042:2000, 5.1 General — Overview

A company, with an integrated system of timberland and diverse forest products, conducts an LCIA with the goal of ascertaining the relative impacts of the issues of climate change on a variety of the corporation's operations, and specifically to ascertain the

- net contribution to greenhouse gases (GHG) from carbon (C) emissions and sequestration and carbon sinks,
- potential for C credits, joint projects or trading,
- allocation of responsibilities among different actors in the product life cycle, and
- opportunities for environmental and economic improvements.

The scope of the study involves a comprehensive approach to identify and quantify not only traditional impact categories and indicators for GHG emission, but also for carbon sinks both in timberlands and along the product system. In that context, the example identifies specific inventory results and transformation models that are an indispensable part of the scope of the study in order to achieve the intended goal.

6.4.2 ISO 14042:2000, 5.2 Concept of category indicators

The example illustrates five major lessons:

a) the need to consider other parameters, in addition to quantification of traditional emissions or resources, through definition of a new impact category. This is necessary in order to meet the goal and scope requirements of the study. Such consideration is anticipated in ISO 14042:2000, 5.3.1;

b) in studies involving biomass and bio-based products, certain transformations within the system boundary have the character of impact categories themselves;

c) indicators result that, when presented in the LCIA results profile, could be additive across impact categories under certain design and selection conditions;

d) information can help ascertain the shared responsibilities of different actors in the product system according to the effects and impacts;

e) the application of LCIA can be expanded to specific company situations for policy and strategic planning.

6.4.3 ISO 14042:2000, 5.3 Selection of impact categories, category indicators and characterization models

6.4.3.1 General

Subclauses 6.4.3.2 to 6.4.3.5 describe the major steps in the selection of the impact categories. Subclauses 6.4.3.6 to 6.4.3.8 describe the steps in the selection of the indicators, mechanisms and characterization models and factors. By illustration of ISO 14042:2000, 5.4, the procedures to assign LCI results to the impact categories are indicated, and by illustration of ISO 14042:2000, 5.5, (characterization), the indicator results are calculated and the profile generated.

6.4.3.2 Consistency between impact categories and the goal and scope of the study

The goal of the study is to ascertain the relative impacts of the company's various operations on the issues of climate change, in a manner that permits assessing opportunities and consequences of different aspects of domestic legislation and international treaties.

The variety of forest products manufactured by the company can be classified as paper products and wood products. Among the first group are market pulp, printing and writing papers, packaging board and tissue products. Wood products range from lumber to structural wood panels. A variety of engineered wood products, such as MDF, OSB, particleboard, waffle board, etc., are included in the second group. All these products have a common characteristic: their carbon content.

The use of one million metric tons (1×10^6 t) of product carbon content as the functional unit is compatible with the goal of the study, since it facilitates the different calculations in the conversion of inventory results into impact categories and indicators. The selection of impact categories shall be consistent with the characteristics of the system as well as the goal and purposes of the study. In other words, besides the radiative forcing, which is an impact category indicator for GHG emission sources, the study needs an impact category, carbon sequestration sinks, that addresses the impacts of carbon sequestered and stored in sinks that are recognized as desirable tools for improvement. Moreover, since credits, trading and controls are expressed in terms of net values (emissions minus sinks), the impact categories should provide indicator results that, under specific study design conditions, can be added together at the level of the indicator results profile.

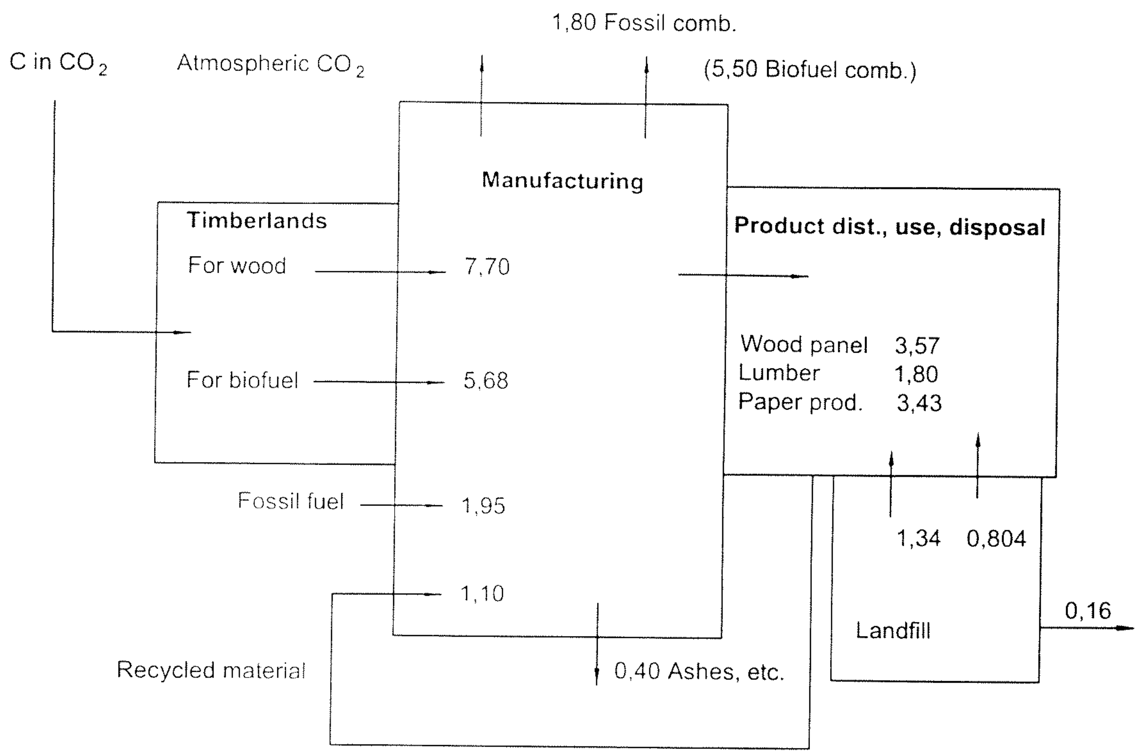
6.4.3.3 Purpose of LCA study and identification of target audiences

The purpose of the LCA study includes gathering the necessary information and data along the product system components that will permit assessment of the net impacts of both GHG emissions and carbon sequestration and storage in carbon sinks. Such assessment would help in decision-making concerning the company's policies and strategies involving climate change issues. LCIA was considered an additional tool to better understand the inventory issues and information gathered, in terms reflecting the prevailing mechanisms in climate change science and policies [26].

Consequently, the study needs to present information, methods and results in a manner understandable to the company executives responsible for different product lines and administrative functions, while maintaining relevance to climate change terminology and concepts. Additional target audiences are other executives and managers of environmental engineering, government affairs, technology, public relations, production, etc. The original complete study is considered of a confidential nature. In this example, the company's structure and size at the time of the study are different from those of the company today.

6.4.3.4 Review of the LCI system functions, boundaries and unit processes

Figure 7 presents a simplified schematic diagram of the product system and its boundaries, with some of the production distribution, that will be used and transformed in the characterization step of the LCIA. In terms of carbon (C), atmospheric CO_2 is captured in the timberlands, trees are grown and harvested. Biomass C enters the manufacturing stages either as wood for wood and paper products, or as bio-fuel. C is emitted as CO_2 from the combustion of biofuels and fossil fuels. Products of different natures are manufactured, distributed, used and disposed of. All quantities cited are in annual terms. The example does not address C emissions from fossil fuels in timberland operations, nor in transportation and distribution. These contributions are small in comparison with other contributions.



NOTE For some parts of the system, the arrows represent selected flows (for illustrative purposes). Consequently, for these parts of the product system the inputs and outputs do not add up to the same amount of carbon.

Figure 7 — The product system in terms of carbon (expressed in metric tons × 10^6)

6.4.3.5 Identification of a comprehensive set of environmental issues related to the product system

The goal and scope of the study help define a comprehensive set of environmental issues inherent in the product system. This set shall include both the traditional emissions of anthropogenic fossil fuels and GHG, as well as those reflecting sequestration of C from atmospheric CO_2 and its storage in sinks along the product system. To assess the relative impact of the originally sequestered C along the stages of the product system, it is necessary to quantify specific biomass processing. These quantities will be transformed later during the characterization stage of LCIA. Information is needed on the intended function of the processed biomass, either as biofuels or as different wood and paper products.

Another important environmental issue itself, for the purposes of the goal of the study, is the net growth or balance of carbon sequestered in the forests. This information is provided in terms of merchantable wood and is transformed, by characterization factors, into total biomass C and C-equivalent.

There are also important environmental issues associated with the "net-zero CO_2" mechanism for biomass fuel and the storage in C sinks in forest products. Table 15 provides product functionality information, in accordance with [27] on the biomass processed in accordance with Figure 7.

Table 15 — Functionality of the amounts of processed carbon

Product and functional categories	Percentage	Amount (C) t × 10	Totals t × 10
Biomass			
for combustion as fuels	100 %	5,68	**5,68**
Wood panels for:			
1-family residence	(40 %)	1,44	
multi-family residence	(30 %)	1,07	
upkeep/improvement	(20 %)	0,70	
non-residential use	(10 %)	0,36	**3,57**
Lumber for:			
1-family residence	(30 %)	0,54	
multi-family residence	(30 %)	0,54	
upkeep/improvement	(20 %)	0,36	
non-residential use	(20 %)	0,36	**1,8**
Printing and writing paper	(100 %)	1,43	**1,43**
Other paper/paperboard	(100 %)	2,00	**2,00**
Grand total			**14,48**

6.4.3.6 Selecting the impact categories

According to the above considerations and the goal of the study, it was decided to select two impact categories. We wish to protect the climate against, or minimize, the imbalance created by the anthropogenic GHG and its actions. The inventory results can be assigned to these impact categories. This consideration fits the definitions in ISO 14042:2000, Clause 3. The two impact categories chosen for the study are:

a) climate change with radiative forcing as the indicator;

According to the IPCC, this category reflects the quantifiable imbalance that anthropogenic GHGs create between absorbed sunlight and reflected IR radiation, which is a traditional issue of concern. The inventory results that are needed to initiate the LCIA phase for radiative forcing as an impact category indicator are GHG emissions. They are transformed (via GWP factors) into category indicators and aggregated to yield the category indicator results, metric tons of CO_2-equivalent, or C-equivalent.

b) carbon sequestration and product sinks.

In systems where the resources are biomass, yielding bio-based products and bio-fuels, there is another class of impact category representing environmental issues of concern. This class of impact category is carbon sequestration sinks. Carbon sequestration may be seen as part of the product system. The carbon sinks effects will then be dealt with as part of the inventory analysis and the resulting (negative) CO_2 emissions considered as contributing to climate change. In this example however, the carbon sequestration sink is defined as a separate impact category in parallel with climate change. This impact category can be recognized as one with a reverse sign to the above. The indicator for this impact category is sequestration, because it is recognized that carbon sequestration removes carbon dioxide from the atmosphere and fixes it in carbon sinks in the forest and downstream in the product system.

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Both impact categories are linked to the same endpoint: impacts of the change in the balance created by the absorbed and reflected IR radiation.

When considering carbon sequestration sinks as an impact category, the inventory shall look into the timberland as well as into the product system downstream of manufacture. First it is necessary to quantify the C sequestered in the total forest system (or fibre basket) for the company, and not only on the merchantable amount of wood that is transformed into products. The net growth in biomass C, after discounting for harvesting, represents the C sequestered. Once the atmospheric C is sequestered, it remains stored in the timberland and in the products for a period of time, depending on the type of product and the use to which it is put. Since the biomass for fuels was already discounted as part of the harvested amounts, it is easier to understand the "net-zero" CO_2-equivalent emission in the accounting of net C-equivalents.

6.4.3.7 Describing the environmental mechanism for the impact categories

The environmental mechanism is the system of physical, chemical and biological processes linking LCI results to the category indicators and endpoints for a given impact category. The endpoint for the two impact categories is the same: concern about the damage caused because of the change in the balance between absorbed and reflected IR radiations. The difference in the indicator results for the two categories is one of sign. Those increasing the imbalance are negative influences; those reducing the imbalance by sequestration and delaying the effects by storage in sinks are positive influences. The mechanisms in the example link the LCI results to the impact categories and the indicator results through proper characterization models and factors. Two of the mechanisms are conventional, i.e. radiative forcing and photophosphorylation. The other two mechanisms, retirement curves for products still in use, and landfill sinks, are less conventional, but they both are a system of physical processes for the carbon sequestration sinks that link the LCI results to the category indicators. Although expressed in similar units, the mechanisms and the models provide the separation between the LCI and the LCIA phases of the LCA.

6.4.3.8 Selection of indicators

The indicators for the two impact categories were considered to be tons of CO_2-equivalent or tons C-equivalent. The LCI results expressed in tons CO_2 can be converted into C-equivalent for the same time frame. Likewise, the LCI results having to do with C sequestration and storage in sinks are convertible into CO_2-equivalent with the proper factors and models. It is important to keep similar time frames for both impact categories. Here, the example uses a time frame of 100 years for the GWP factors, as is normally done. For the product sink, we also use a time frame of 100 years for the time a given fraction of the product remains in use and hence can still be considered a carbon sink[3].

6.4.3.9 Selection of characterization models and factors

6.4.3.9.1 The IPCC model for radioactive forcing

The characterization model for the radiative forcing impact category is the one used and fostered by the IPCC. The specific IR radiative forcing for different GHGs permits expressing different GHGs in a common unit, normalized to the value of 1,00 for CO_2. The GWP, as characterization factors, permits different GHGs to be aggregated and expressed in C-equivalent units. IPCC recommends a time frame of 100 years. If the time frame is changed to 500 years or infinity, the methane GWP factor will be reduced considerably. Table 16 gives the GWP characterization factors for the three major GHGs in the example. Nitrous oxides from fuel combustion are negligible and are not included in this example.

3) According to ISO 14042:2000, Clause 5, the modelling of one of the impact categories also includes processes in the product system such as sequestration in timberlands and wood products.

Table 16 — GWP factors

Greenhouse gas	Atmospheric lifetime years	**GWP factor** (100-year time frame)
Carbon dioxide (CO_2)	50 to 200	1
Nitrous oxide (N_2O)	120	310
Methane (CH_4)	12 ± 3	21

6.4.3.9.2 The Calvin-Benson model for carbon sequestration sinks

The characterization model for the carbon sequestration impact category consists of two phases. In the first phase, sunlight energy is converted by photophosphorylation into adenosine triphosphate (ATP) and the co-enzyme NAPDPH, both energy-rich molecules. In the second phase, the Calvin-Benson cycle fixes the atmospheric CO_2 into organic substances, making use of the converted sunlight energy.

The characterization factor that is used with the model converts the net C (T_C) biomass growth/year from the inventory results (expressed as merchantable wood) to gross biomass growth/year, T'_C by multiplying this value by a biomass/merchantable factor. This factor was derived for specific tree species and regions, and equals 1,70. In addition, another correction factor is used to account for the estimated 25 % of biomass left as residues in the forest.

Merchantable wood $\times$ 1,70 = total biomass T_C

$T_C \times 0{,}75$ = useful biomass

6.4.3.9.3 Characterization model for the storing of sequestered carbon in product sinks

To estimate the amount of C-equivalent that can be considered in storage in sinks, an estimate is needed of the rate at which the forest products (and carbon) are withdrawn from use in each end-use sink, according to the functionality of the product. Row and Phelps [27] have developed a characterization model that uses a retirement curve to estimate the proportion (%) of wood products remaining in the end-use sink[28]. It is based on the half-life average and the functional use of the specific product. The Internal Revenue Service (IRS) of the U.S. Department of Treasury generates half-life estimates for a variety of products, according to functional categories such as single-family dwelling, multi-family dwelling, etc. Logically, different kinds of wood products can thus be classified into one given functional category.

The time that a wood product remains in use (t) is determined largely as function of the average useful half-life (L) and the proportion (P) of that product remaining in the sink at a given time. The selected t of 100 years exceeds the higher half-life average value of 67 years. The selection also reflects the 100 years horizon selected for the GWP factors. In this manner, the indicator results from the two impact categories will not only be expressed as C-equivalents, but also in the same time horizon. t and P are expressed as:

$$t = f\left(L, P\right)$$

where $P = 0{,}5 / [1 + 2 (\ln t \; \ln L)]$

6.4.3.9.4 Refining the characterization model and factors

One way to account for recycling is by means of characterization model expressed by an equation developed at the USDA's Forest Service[28]. The official *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000* uses these equations and half-life values as indicated in their latest report[29]. The effect of the equation is to extend the useful half-life of the C stored in a particular product end-use sink. (In other words, the equation extends the range of the numbers given in the IRS tables and consequently increases the value of the characterization factors).

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The equation is given by the expression below:

$$L_r = L/(1 - R)$$

where

L_r is the revised expected half-life;

L is the original half-life and;

R is the proportion of product being recycled into the same product category.

Recycling has the beneficial effect of increasing the characterization factors and thus the C-equivalent in the sink. Its effect is more pronounced in the recycling of products with long half-lifes.

6.4.3.9.5 Characterization model for biomass fuels — Net-zero C

The characterization model that describes the net-zero C emitted when burning biomass fuel is typically a recycling model, in which CO_2 from the atmosphere (and its C expression) are sequestered by the photosynthesis process described in the Calvin-Benson model. Neglecting C^{12} and C^{13} considerations, the CO_2 emissions from the combustion are considered equal to those already sequestered and those that will be subsequently sequestered. This is different from the CO_2 emissions of fossil fuel that result from the use of C from long-term carbon sinks rather than from the atmosphere. The characterization factor used is 0.

6.4.4 ISO 14042:2000, 5.4 Assignment of LCI results (classification)

A brief description of the classification of LCI results into impact categories is given in Figure 8. The classification stage cannot be completed until there is reasonable certainty of the availability of adequate characterization models and factors. They will yield indicator results to be described in the indicator results profile.

6.4.5 ISO 14042:2000, 5.5 Calculation of category indicator results (characterization)

6.4.5.1 General

Characterization involves the conversion of the LCI results (million tons C per year) into common units using the characterization factors derived according to the characterization models. A simplified version of the necessary calculations, grouped according the two impact categories, is presented below. Table 17 provides a summary of the calculations leading to indicator results. P_C is the proportion of carbon in the annual production of different forest products, e.g. solid wood and paper, in million tons C per year. P_l is the proportion of carbon in the same types of product which is estimated used as landfill in a year. P_f is the proportion of carbon in the product biomass fuel used in a year. The following matrix indicates the LCI results, characterization factors and indicator results for the different impact categories and indicators.

6.4.5.2 C sequestration and sinks and net-zero for biomass fuel

T'_C indicates the gross biomass growth per year in million metric tons C per year. P'_f is the product biomass fuel carbon emissions, in million metric tons per year, that yields a net zero. P'_C refers to the product carbon remaining in storage, expressed in million tons carbon per year. It is subdivided according to the functionality of the different forest products.

6.4.5.3 C emissions from fossil fuels and methane from landfill

Ff_C addresses the fossil fuel carbon emissions, in millions tons per year. The term L'_C refers to the carbon estimated going to landfills from the total annual production of the company, in million metric tons. This element of the characterization stage is the weakest in accuracy and more work is done to improve its reliability both in the US EPA model and database. Besides a net zero contribution from CO_2 releases, there is a methane contribution that is part of the radiative forcing impact category. The characterization models and factors are both IPCC and US EPA.

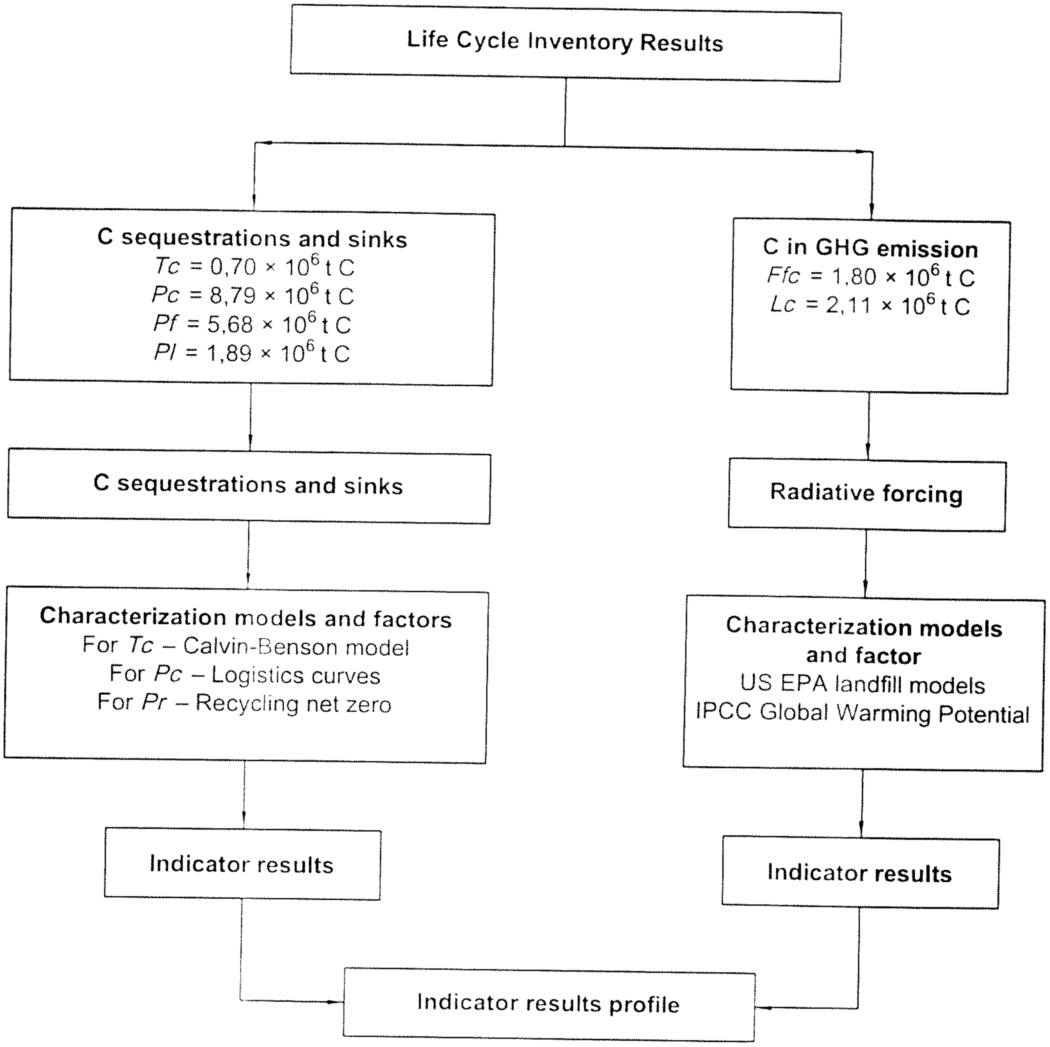

Figure 8 — Schematic of the LCI results assigned to impact categories

Table 17 — Calculation of indicator results

LCIA Indicator	LCI result t C × 10^{-6}	Characterization factors	Indicator results[a] t C-eq × 10^{-6}
$T'c$	**0,70**	**× 1,70 × 0,75**	**0,89**
$P'f$	**5,68**	**Net zero**	**0,00**
P'_C	9,23	Various (see below)	**1,49**
Wood panels for:	3,56		**0,81**
• 1-family dwelling	1,44	0,25	0,36
• Multi-family dwelling	1,07	0,20	0,24
• Upkeep/improvement	0,70	0,15	0,11
• Non-residential	0,36	0,27	0,10
Lumber for	**1,80**		**0,39**
• 1-family dwelling	0,54	0,25	0,13
• Multi-family dwelling	0,54	0,20	0,11
• Upkeep/improvement	0,36	0,15	0,05
• Non-residential	0,362	0,27	0,10
Printing and writing papers	1,80	**0,18**	**0,18**
Other paper/paperboard	2,00	**0,05**	**0,10**
$F'f_C$ **(fossil fuels)**	1,80	1,00	**1,80**
L'_C **(landfill)**	2,14	**21,0 and others**	**1,30**[b]

NOTE In addition to the factor 7,7 for conversion of methane carbon to CO_2 carbon, other conversion factors are used in the US EPA model.

a Table 17, Column C equivalents. The table is based on the C amount in the different flows, which for methane would lead to a characterization factor of 7,7 kg CO_2-C/kg CH_4-C. The methane characterization factor of 21, which is applied, is valid for methane as such. The difference has been accounted for.

b Table 17, final column, last row. The landfill model calculates the fraction of deposited C which is emitted as CO_2 or CH_4 throughout the existence of the landfill. It is recognised that the landfill model needs improvement.

6.4.5.4 Impact indicator results profile

Table 18 depicts the components of the LCIA indicator results profile (LCIA profile). The results from each impact category are illustrated in terms of the company and the forest products system. This is convenient for two reasons. In the estimation of net growth of C sequestered in timberlands, the company's is only 25 % self-sufficient. The study considers that the remaining 75 % wood fibre supply from small tree farms, etc. reflected similar net growth in the average. This assumption is in line with the trend from regional inventories conducted by state and federal agencies. The second reason is that the methane releases from municipal landfills are part of the forest product system but not of the company. The C-equivalent units for these results are additive, since the C-equivalent on some of the conversions were made compatible for this purpose. In estimating the C-equivalent for the storage in sinks in the product system, 100 years was considered in the logistic curve model. Likewise the IPCC model, for the conversions of methane into C-equivalents, was based on the 100 year time frame. Some research uses a 500 year time frame for the IPCC model. Such an approach lowers the C-equivalent results (for methane the factor will be then 12 rather than 21). If for the product sink model we had used 50 years rather than 100 years, the storage amount would have been higher. These considerations are important to note for the validity of the results.

Table 18 — LCIA profile (per FU)

Impact category	Indicator results			
	Company		Product system	
	t C-eq. × 10^{-6}	per FU	t C-eq. × 10^{-6}	per FU
Radiative forcing				
Manufacturing emissions	1,80	0,195	1,80	**0,195**
Landfill (methane emissions)			1,30	**0,141**
C-sequestration and sinks				
Forest	– 0,88	– 0,095	– 3,52	**– 0,381**
Product sinks	– 1,39	– 0,15	– 1,39	**– 0,15**
Net	– 0,47	– 0,052	– 1,81	**– 0,196**

6.4.5.5 Preliminary analysis and conclusions

Internally, the company's management considered the results responsive to the objectives that originated the study. Conclusions and decisions as a result of the study are considered confidential. For the first time, the issues regarding C-sequestration and storage in sinks were put in an LCIA context. The results provide valuable insights on the issues around net GHG emissions, credits, future trading and the role of different actors in the product chain. Other considerations address the issues of validating and apportioning the net growth in C-sequestration from small landowners and from landfill emissions.

The net profile indicated, for the conditions of the study, a positive balance (sinks and net sequestration cancelled and improved on the GHG emissions). Conditions could change without proper incentives. The results emphasize the positive contribution of sustainable commercial forestry and the use of forest products and biomass. In the same manner, the use of fossil fuels has created an imbalance, but the use of biomass products could help regain that balance. Likewise, the need for proper design and construction of public municipal landfills appears of importance and out of the company's hands.

6.5 Example 4 – Assessment of endpoint category indicators

6.5.1 ISO 14042:2000, 5.1 General — Overview

The purpose of this example is to illustrate the use of category indicators at endpoint level when used for internal purposes only in the area of product improvement. The most important reason for choosing the impact category indicator at endpoint level is the high degree of environmental relevance, which makes interpretation and weighting relatively easy in comparison with indicators chosen near the LCI results. The consequence of modelling at endpoint level is that the whole environmental mechanism between LCI results and endpoints must be modelled. This can lead to higher uncertainties and the need to incorporate more value choices, but lower uncertainties in the interpretation of the results. Clearly there is a trade-off between these uncertainties.

The example is based on a study commissioned by the Dutch government that set out to develop a methodology that can be used by designers. Earlier studies had shown that designers benefit from having single scores per material or process that represent the total environmental load. The purpose of calculating single scores[4)] is to provide an easy-to-use tool for product designers to support their day-to-day design decisions (internal applications) in the development of complex products with many components and materials. Such a single score can only be achieved if some form of weighting is used. The example used here does not

4) ISO 14040:1997, 4.1, refers to single scores and how there is no scientific method to reduce LCA results to a single score.